SEASONAL TEMPERATURE AND PRECIPITATION TRENDS AT FIVE MINNESOTA STATIONS*

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ABSTRACT

Seasonal and annual temperature and precipitation changes at five Minnesota stations considered as climatological reference stations were calculated during several extended time periods. For 1900–58 winter temperatures increased most and a decreasing fall precipitation trend was found. With a longer period, initial date earlier than 1900, fall temperature increases nearly equalled those of winter. A declining, though nonsignificant, seasonal and annual precipitation trend was noted in a majority of the station records.

1. INTRODUCTION

With few exceptions long-term climatic trend studies have dealt exclusively with changes found in the annual or summer and winter periods. Results of these studies often indicate that the climate of the neglected seasons may have experienced equal or greater changes. Such a possibility led to the undertaking of this study, which is an extension of a previous paper on the temperature trends in Minnesota [1]. The objectives were to determine the order and magnitude of the seasonal and annual temperature and precipitation trends at selected Minnesota stations.

2. STATION LOCATION AND DESCRIPTION

Station and record descriptions are shown in table 1. The five stations, Leech Lake Dam, Pine River Dam, Pokegama Dam, Sandy Lake Dam Libby, and Winnibigoshish Dam, have been subjected to only slight changes in local environment. The two most widely separated stations are but 55 miles apart and the vegetation in this region is largely coniferous forest. Nearest cities of importance are Fargo-Moorhead, Duluth-Superior, and Minneapolis-St. Paul, which are about 115 miles west, 55 miles east, and 120 miles south-southeast respectively. These five stations are believed to meet the requirements of the bench-mark ideal. Four of these stations were submitted by the state climatologist to the U.S. Weather Bureau Office of Climatology as possible sites for a climatic reference or bench-mark station. They were rejected, however, in favor of a University of Minnesota biological and forestry station where less doubt existed as to the future of the site [2].

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3. CALCULATIONS

Each season was considered as a 3-month period and the first month of spring, summer, fall, and winter was March, June, September, and December, respectively. Average monthly temperatures were obtained from U.S. Weather Bureau publications. The few missing data were supplied by standard Weather Bureau procedure.

On the assumption of a linear trend in temperature and precipitation with time, the line of best fit was determined by the method of least squares. The hypothesis that the regression line slope equalled zero was statistically tested assuming normal distribution about the linear trend line. Temperature and precipitation changes noted in this study refer to the difference between the first and last value of the linear regression line.

The five stations were analyzed statistically both as individual stations and as one single station by averaging both the seasonal and annual data.

4. RESULTS

The seasonal and annual temperature and precipitation changes, 1900–58, are shown in table 2 and the total record period in figure 1. Principal features to be noted in table 2 are (a) the winter warming trend, (b) appreciable summer temperature increases at two stations, (c) negligible or even negative temperature changes in the other seasons, and (d) the only definable trend in precipitation being one of decline in the fall.

However, when longer periods were considered (table 3), fall temperature increases were nearly equal to those of winter and exceeded those of summer and spring at every station. Seasonal temperature trends were large enough during the longer time period that not only were annual increases larger than those of the 1900–58 period,

TABLE 1.—*Description of stations and records* [3], [4]

Station	Latitude	Longitude	Altitude	Site	Record
	° ′	° ′	ft.		
Leech Lake Dam	47 15	94 13	1,301	Dam tender's residence; forest 300 feet to south; reservoir to north	Homogeneous.
Pine River Dam*	46 40	94 07	1,251	Dam tender's residence; rolling forest country; lake 300 feet to west	Do.
Pokegama Dam	47 15	93 35	1,280	Dam tender's residence; 300 feet to forest; Mississippi River nearby	Do.
Sandy Lake Dam Libby	46 48	93 19	1,234	Dam tender's residence; woods 320 feet distant; water within 80 feet	Do.
Winnibigoshish Dam	47 26	94 03	1,315	Dam tender's residence; on bank of Lake Winnibigoshish which is surrounded by forest.	Do.

*Rain gage moved 30 feet in September 1954.

TABLE 2.—*Seasonal and annual temperature (° F.) and precipitation (in.) changes for the period 1900–1958*

Station	Spring		Summer		Fall		Winter		Annual	
	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
Leech Lake Dam	0.7	0.21	2.4	0.10	1.6	*−0.72	*4.7	−0.04	2.4	−1.47
Pine River Dam	−.4	.09	.0	−.17	−.1	*−.73	*4.1	.28	.8	−1.66
Pokegama Dam	.5	.32	*2.1	.28	1.6	−.44	*3.7	.15	*1.9	.87
Sandy Lake Dam Libby	−.2	.52	1.0	.70	.2	−.23	*3.5	.11	1.2	3.31
Winnibigoshish Dam	−.7	.12	.6	−.40	.1	*−.63	2.0	.14	.5	−2.37
Average of above stations	.0	.25	1.3	.10	.7	*−.55	*3.6	.13	1.3	−.18

*Slope of linear trend line significantly greater than zero at 5 percent level.

TABLE 3.—*Seasonal and annual temperature (° F.) and precipitation (in.) changes for indicated periods*

Station	Period	Spring		Summer		Fall		Winter		Annual	
		Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
Leech Lake Dam	1888–1958	*2.4	−0.15	**2.0	−0.05	**3.3	−0.28	*3.3	−0.15	**2.9	−1.84
Pine River Dam	1887–1958	.9	−.08	−.9	−.16	1.9	−.12	*4.1	.06	*1.4	−1.13
Pokegama Dam	1888–1958	*2.3	−.15	*1.9	−.36	**4.5	−.10	**4.4	−.15	**3.3	−2.38
Sandy Lake Dam Libby	1893–1958	.5	.11	.7	.81	1.7	−.08	*3.8	−.08	*1.6	2.03
Winnibigoshish Dam	1888–1958	1.3	−.16	*1.5	−.39	*2.3	−.35	1.6	.01	*1.7	−2.59
Average of above stations	1893–1958	.9	−.17	1.0	−.01	2.0	−.40	*4.3	.01	**1.9	−1.93
Average of above stations	1887–1958	1.6	−.01	1.0	−.06	**3.0	−.15	*3.5	−.08	**2.2	−.84

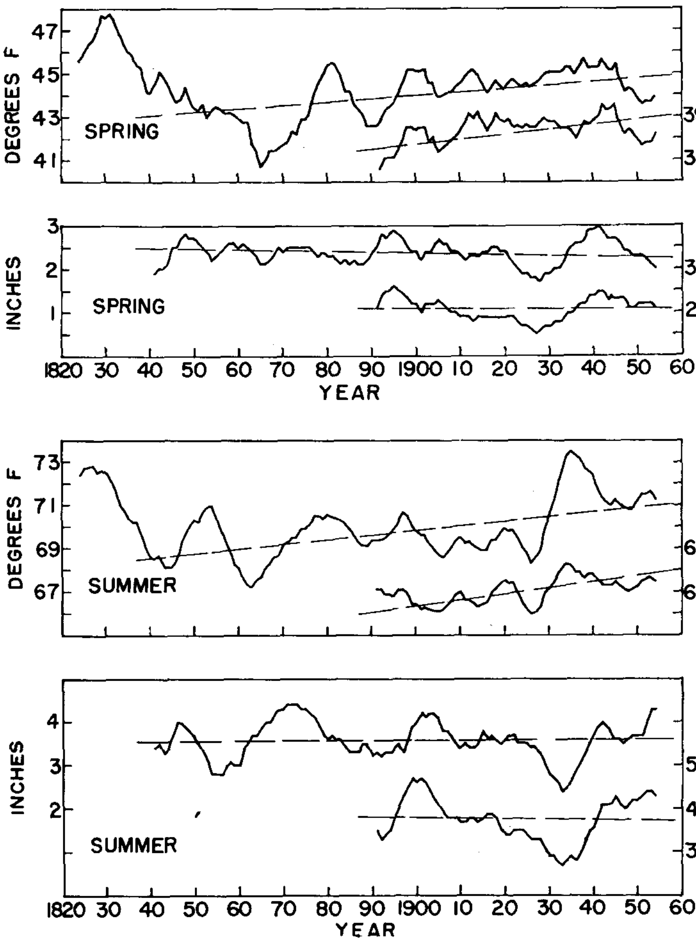
*Slope of linear trend line significantly greater than zero at 5 percent level.
**Slope of linear trend line significantly greater than zero at 1 percent level.

but the slopes of the linear trend lines were significantly greater than zero at each station.

Seasonal precipitation changes were negligible in amount with decreases in the majority. The annual changes of precipitation were appreciable and all were negative except at Sandy Lake Dam Libby. No explanation can be offered for this discrepancy. Because linear trend lines were nonsignificant these decreases cannot be considered important except perhaps in indicating a tendency.

Landsberg [5] in a study similar to this one computed seasonal and annual temperature and annual precipitation changes between averages for the periods 1901–30 and 1931–55 at 48 United States stations. One Minnesota station was included, located in the town of Park Rapids, which is not far from the stations used in this study. General agreement between this study for the period 1900–58 and that of Landsberg was found. However, two differences might be mentioned. In contrast to Park Rapids none of the stations in this study had greater summer than winter increases, and three of the five indicated a decreasing, though nonsignificant, annual precipitation trend. Reconciliation of these differences is not difficult. A slight change in time periods, as already noted, can greatly alter the magnitude of changes and seasonal ranking. For example, Cloquet Forest Research Center and Itasca State Park, both in northern Minnesota and the latter now designated as a climatic reference station by the U.S. Weather Bureau, have had significant annual total precipitation increases of 5.17 and 5.34 inches, respectively, for the period 1912–58. As inspection of figure 1 shows, the later the initial year is after 1900 the greater is the indicated total annual precipitation increase. There is in addition the fact that the usual precipitation sampling techniques are poor, which Landsberg noted. The differences found between this and the study by Landsberg do, however, indicate inherent difficulties in comparing studies not exactly alike. They may also illustrate differences that occur between stations considered reliable.

The severity of the drought in the 1930's is clearly shown in figure 1, particularly in the annual data. The smoothed data (fig. 1) show that the precipitation total began to decline in the early 1900's, a feature not generally recognized, and progressively decreased almost without a break until about 1933 in northern Minnesota. Much



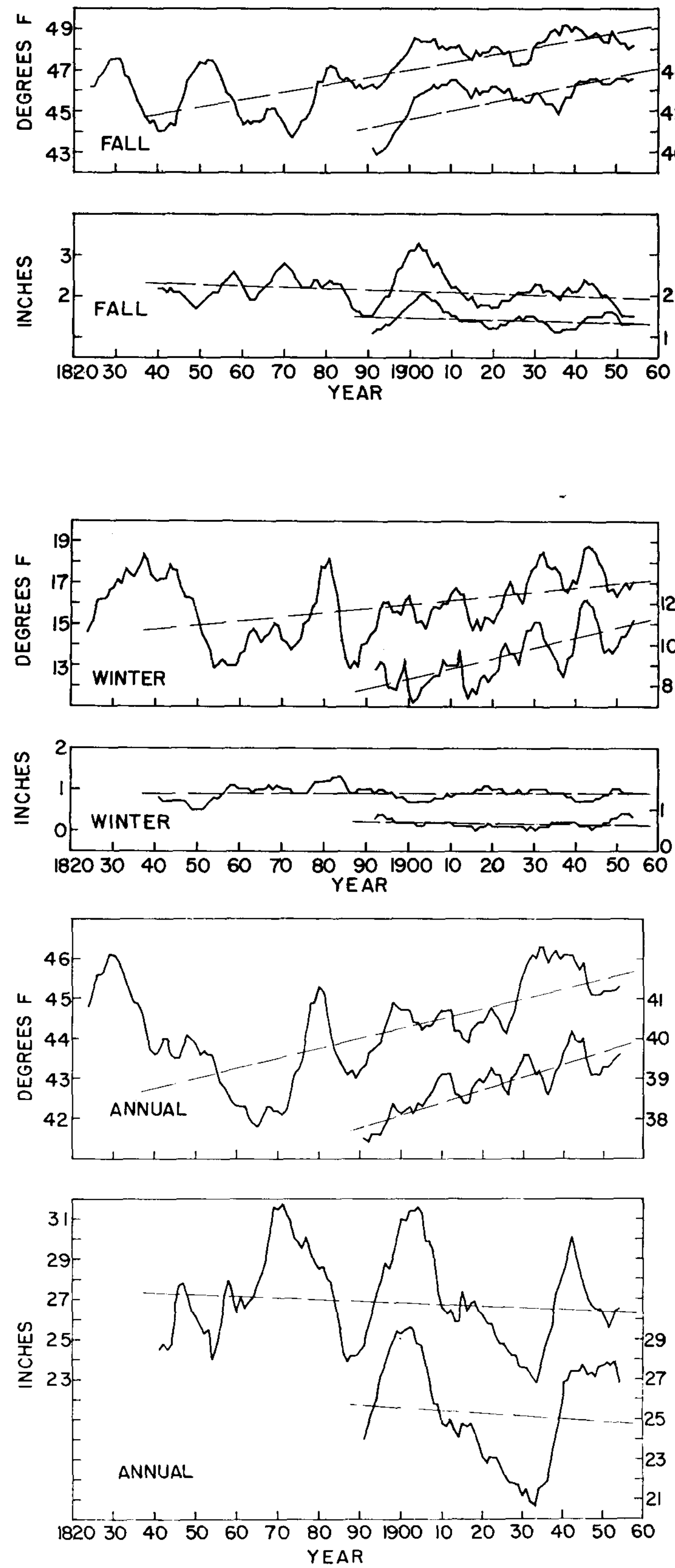


Figure 1.—Time series of mean seasonal and annual temperature (° F.; top half of each pair of panels) and precipitation (in.; bottom half of each pair of panels) for St. Paul (longer record; scale at left) and the average of the five northern stations (shorter record; scale at right). Data were smoothed by a normal curve smoothing function of length $2\sigma=9$ years [6]. Values were plotted at midpoint of smoothing interval. Dashed lines show linear trend of temperature and precipitation for period 1837–1958 at St. Paul and 1887–1958 at the five northern stations.

to the State's good fortune the feature of declining precipitation with the rapidly rising summer temperatures of the late 1920's and early 1930's was a unique occurrence considering duration and intensity. The nonhomogeneous, and in a few cases highly suspect, St. Paul record has been included in figure 1 to show that this combination of high temperature and low precipitation was apparently never before realized within at least the last century. There was a sharp precipitation drop in the 1880's, but this was at least partially offset by declining temperatures, and the relatively short duration of the precipitation decrease prevented serious repercussions. The annual record (fig. 1) indicates that the drought of the 1950's was not severe in this area.

More or less as an aside and as a result of a comparison made between some long-term records, curiosity was aroused as to the congruity of the records in indicating commencement of the recent warming trend. Table 4 was the result. Temperature data were taken largely from the paper by Kincer [7]. It should be noted that

TABLE 4.—*Date of occurrence of seasonal and annual minimum temperatures (° F.) 1820–1900 and maximum temperatures after 1900*

Station	Spring		Summer		Fall		Winter		Annual	
	Year	Temp.	Year	Temp.	Year	Temp.	Year	Temp.	Year	Temp.
	Minimum temperatures, 1820–1900*									
Copenhagen, Denmark	----	----	----	----	----	----	----	----	1841	43.9
New Haven, Conn	1871	44.1	1856 1888	68.4 68.4	1838	49.3	1869	26.3	1836	47.6
Philadelphia, Pa	----	----	----	----	----	----	----	----	1839	51.4
St. Louis, Mo	----	----	----	----	----	----	----	----	1853	54.7
St. Paul, Minn	1865	40.7	1863	67.2	1872 1841	43.7 44.0	1854 1886	12.9 12.9	1865	41.8
Washington, D.C	1866	51.9	1863	73.7	1840	53.9	1869	33.4	1840 1859	53.6 53.9
	Maximum temperatures after 1900*									
New Haven, Conn	1921	49.1	1935	71.4	1945 1931	54.8 55.0	1953	33.0	1931	52.1
St. Paul, Minn	1942 1938	45.7 45.7	1935	73.5	1949	48.9	1943	18.8	1942 1934	46.1 46.3
Washington, D.C	1945	56.8	1953	77.1	1945	59.8	1953	39.7	1953	58.1
Northern Minnesota Stations	1945	39.6	1934	66.3	1945 1954	43.6 43.6	1943	12.2	1942	40.2
Winthrop College, S.C.**	----	----	1936	79.0	----	----	1951	46.1	----	----

*Dates and temperatures obtained from data smoothed by normal curve smoothing function of length $2\sigma=9$ years. Secondary maxima and minima were also included when of equal or nearly equal degree.
** Dates and temperatures estimated from figure 6 of "Trends in Climatology" [8].

the information in table 4 was obtained from data smoothed by the normal curve smoothing function [6] of length 2σ equal to 9 years. The dates therefore may not coincide with the absolute record maximum or minimum, which, often being anomalous, may have little or no bearing upon long-term trends.

If only the annual temperatures are considered, mid-19th century (plus or minus about a decade) marks the commencement date. Of interest, and possibly importance, was the lag in occurrence of the minima at the continental stations, St. Louis and St. Paul, when compared to the other stations, all of which are under some maritime influence.

Also in table 4 are the dates of peak seasonal and annual temperatures within the period 1900–1958. Good agreement between stations was found with two exceptions. The first was the anomalous 1921 spring maximum at New Haven, and the second was the differential in winter maxima which occurred first in Minnesota and about a decade later at the east coast stations. At some other Minnesota stations the peak was reached in the 1930's [1]. Judged by the reference stations included, this 10-year differential was apparently real.

The lags in temperature maxima and minima may explain in part why regions even of nearly equal latitude compared on a uniform time basis do not show equal changes. If the regions were compared from time of minima to time of maxima, which might be over the same length of time but not over the same years, a portion of the differences found might disappear.

5. SUMMARY

Seasonal and annual temperature and precipitation changes were determined, based upon records of five northern Minnesota stations believed to fulfill the climatological bench-mark or reference-station ideal.

During 1900–1958 winter temperatures increased most and summer increases were secondary. Temperature changes in the spring and fall were negligible. A declining trend was evident in fall precipitation.

Over a longer period, 1887–1958, fall temperature increases nearly equalled the well known winter increase. Summer and spring changes were slight. A possible trend toward declining precipitation was indicated in all seasons and annual totals at a majority of the stations.

Long-term temperature records indicate that the recent warming trend began about 1850, plus or minus about a decade, and the peak was reached in about 1940 at Minnesota and a decade later at east coast stations.

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